RESEARCH ARTICLE

Experimental Analysis of Non-Destructive Testing (NDT) on Ground Granulated Blast-Furnace Slag (GGBS) based Geopolymer Concrete

Shabarish V. Patil, Sachin Chabbi, Soundarya Chabbi, Nikhil Pudakalkatti, Pavana Patil

Department of Civil Engineering, KLE Institute of Technology, Hubballi, opposite to Airport, Gokul Road, Hubballi – 580 030, Karnataka, India

ABSTRACT: Geopolymer is a type of concrete that has become more popular in recent years due to the fact that is significantly more environmental friendly than standard concrete. Geopolymer Concrete is produced by reacting with high rich aluminate and silicate bearing materials using an alkaline activator solution. In this present work, the suitability of non-destructive method to find the compressive strength of geopolymer concrete will be analyzed. The comparison of the compressive strength with both destructive and non-destructive method is checked for M30, M40, and M50 grade of geopolymer concrete cured in an oven and in ambient temperature condition. The calibration curve and regression curve for all the grades of concrete for the obtained rebound number is plotted. The alkaline liquid used in this study for the geopolymerization is sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Different molarities of sodium hydroxide solution (8M &10M) are used suitably to prepare different grades of concrete cubes. The compressive strength test of geopolymer concrete cubes of size 150×150×150mm is tested at the age of 28 days for the experimental analysis.

KEYWORDS: Geopolymer concrete, GGBS, Compression strength, Non-destructive testing, Destructive testing,

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1. INTRODUCTION

The second largest used material in the world is concrete. The main problem associated with the normal concrete is high emission of CO_2 into the atmosphere [15]. It is estimated that 2.2 billion tons of cement are consumed by every year [17], so it releases an equal quantity of carbon dioxide into the atmosphere [16].

In order to reduce the CO_2 emission by the concrete into the atmosphere, an alternative binder for the concrete was developed by Davidovits in the year 1978, i.e. geopolymer technology [6]. Geopolymer concrete is produced by the alkali activation of silicon and aluminium-rich materials combining with aggregates. The main factor which defines the properties of geopolymer concrete is Aluminium silicate-rich materials, molarities of NaOH [13], superplasticizer [9], and curing conditions [11]. The geopolymerization process involves dissolution of silicon and aluminium ions from the amorphous phases of binder like GGBS and involves condensation of silicon or aluminium hydroxide molecules to form an oxygen bond connecting silicon and aluminium hydroxide molecules and free molecules of water and it also involves polymerization monomers and other silicon molecules and aluminium hydroxide molecules condense to form rigid chains of oxygen bonded tetrahedrally with the application of small temperature or even at ambient [4].

In this study, GGBS is used as source material in the geopolymer concrete. The compressive strength of GPC was evaluated using non-destructive testing and destructive testing method. Based on relative literature, the effect of Molarity of NaOH and curing conditions of GPC on Compressive strength, SRH has been discussed in the following sections.

2. COMPRESSIVE STRENGTH

The Compressive strength of concrete gives an idea about all the characteristics of concrete. The Compressive strength test is carried out either on cube or cylinder. The IS 516-1959 provides standard test method for Compressive strength of the concrete. Compressive strength is an ability of concrete structure to carry the loads on its surface without any failure. The field compressive strength of concrete under service can also be predicted by Non-destructive testing methods such as rebound hammer [19].

3. SCHMIDT REBOUND HAMMER (SRH)

The rebound hammer method consists of impacting the concrete surface in a standard manner [5]. Activating a mass by a given energy and measuring the indention or the rebound achieves this. The most frequently used instrument is rebound hammer. There are several types of hammer having varying impact energy from 0.07 kg-m to 3kg-m; the high impact energy is used for mass concrete, road pavements and airport runways. The low impact energy hammers (0.07-0.09kg-m) are used for small and low strength materials. The rebound hammer used in the present research is shown in Fig 1.

3.1 TEST PROCEDURE:

The test procedure involves the application of rebound hammer into the concrete surface and the readings are observed on rebound hammer indicated by the rider

Corresponding Author:* ***shabarish633@gmail.com*

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over a scale. Before applying the hammer, the surface of the concrete is cleaned and smoothened. A minimum of 10 readings are compared and each reading should not differ by more than 7 units. The average of remaining readings is determined for evaluating the strength. If more than two readings differ from the average by 7 units, then the entire set of readings is taken afresh [18].

The procedure for determining the rebound values has been specified in ASTMC 805-85, BIS-13311 Part2 and also in the latest ASTM specification [18]. Estimation of concrete compressive strength from the rebound number is determined from the standard calibration curve based on the laboratory results. The calibration curve should be established for each type of concrete. There are many factors which affect the rebound number like size and age of concrete, surface texture, concrete mix characteristics, temperature and stress state, the Carbonation level in concrete and moisture content [8].

It should be found that the rebound values reflect the concrete quality up to a depth of 50mm in the member. In a practical situation, the strength prediction can be made to an accuracy of 25%. The surface hardness measurement can be used for checking the uniformity of concrete, differentiating a given concrete with a specified requirement, approximately estimation of strength by using laboratory calibrated graphs

Fig.1 Digital Schmidt rebound hammer

4 EXPERIMENTAL SET-UP

The present work involves the determination of compressive strength of GGBS based geopolymer concrete by using non-destructive testing method i.e., by the rebound hammer method. In this study, three different grades of geopolymer concrete were prepared i.e. M30, M40 & M50 grades of GPC. Coarse aggregates of size 20mm and 12.5mm are used in the proportion of 60:40. Ground granulated blast furnace slag was used as a geopolymer binder. The sodium silicate and sodium hydroxide were used as an alkaline activator solution. The compressive strength was determined at the age of 28 days of curing at ambient and oven temperature. The calibration curves and regression curves for compressive strength with respect to SRH are represented and these results are compared with the results of destructive testing.

5 MATERIALS

The materials used for making GGBS based geopolymer concrete specimens were GGBS as the source material, aggregates, alkaline solution, water, and super plasticizer.

5.1 GROUND GRANULATED BLAST FURNACE SLAG (GGBS)

It comprises mainly of calcium oxide, silicon di-oxide, aluminium oxide, magnesium oxide. The different composition of GGBS presented in Table 2. It has the same chemical properties as ordinary Portland cement but in different proportions and the addition of GGBS in geopolymer concrete (GPC) increases the strength of the concrete and also curing of Geo-Polymer concrete at room temperature is possible [10]. GGBS was purchased from JSW Industries Hubballi Karnataka. The specific gravity of GGBS is presented in Table 3.

5.2 FINE AGGREGATE

Coarser sand is used as a fine aggregate in experimental work. It is obtained from a local quarry. By using the pycnometer instrument specific gravity of sand is calculated. The test results of fine aggregate are shown in Table3.

5.3 COARSE AGGREGATE

Local aggregates, comprising 20 mm and 12.5mm coarse aggregates and fine aggregates, in a saturated surface dry state, were used. The type of coarse aggregates were used in this work is crushed granite-type aggregates and the fine aggregate was fine sand. The test results of coarse aggregates are presented in Table 3.

5.4 ALKALINE ACTIVATOR SOLUTION

In the Geopolymer concrete, alkaline activator solution is very important material. The most common alkaline activator solution used in geopolymerization is a mixture of Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) [7]. In this experimental work Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) were used as an alkaline activator solution.

5.5 SODIUM HYDROXIDE

The sodium hydroxide solids of a laboratory grade in pellets form with 99% purity were used. The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets in water. The mass of sodium hydroxide solids in a solution varied depending on the concentration of the solution expressed in terms of molar M. For example, sodium hydroxide solution with a concentration of 8M consists of 8x40= 320 grams of sodium hydroxide solids (in pellet form) per liter of the solution, where 40 is the molecular weight of sodium hydroxide.

Table 1 Quality of concrete cover from rebound number

Average rebound number	Quality of concrete
Greater than 40	Very good hard layer
30-40	Good layer
20-30	Fair
Less than 20	Poor concrete
0	Delaminated

Table 2.General Chemical Properties of GGBS in (%) (C Sreenivasulu 2018[2])

Particulars	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	SO_3	LOI[a]
GGBS	30.61	16.24	0.584	34.48	6.79	-	1.85	2.1

Table 3.Physical Properties of Aggregates

Particulars	Coarse Aggregate		Fine Aggregate	
	20mm	12.5mm	Sand	GGBS
Bulk Specific gravity	2.89	2.52	2.83	1.56
Water Absorption (%)	1.01	1.01	1.0	-

Table 4.Constituents of sodium silicate solution

Na_2O (%)	SiO_2 (%)	Water (%)
14.7	29.4	55.9

5.6 SODIUM SILICATE
Sodium Silicate in gel form is obtained from Local manufacturer. The specifications of sodium silicate are given below in Table 4.

5.7 SUPERPLASTICIZER
In order to achieve the design strength, 1-1.5% of the binder content was taken as superplasticizer quantity. In this present work, the type of superplasticizer used is MGlenium SKY 8233 (Polycarboxylic ether based).

5.8 WATER
Tap water was used to prepare the solution of NaOH and it is also used as extra water required in mixing of geopolymer concrete.

6. MIXTURE PROPORTIONS
Based on the relevant literature, three mix designs are made, which are M30, M40 & M50. In the design of geopolymer concrete mix, the density of GPC is assumed as similar to the density of OPC i.e. 2400 kg/m^3 [16]. The mass of coarse and fine aggregate is assumed as 75-78% of the total density of concrete by mass [16]. The fine aggregate was taken as 30% of the total mass of the aggregates [14]. The GGBS was used as binder content of GPC. The molarity of NaOH was taken as 8M for M30 grade of GPC and 10M for M40 & M50 grade of GPC. The mix proportions of different grades of GPC are shown in Table 5. 7.

7. METHODOLOGY
GPC is a new constructional material which has developed in recent decades [3]. So there is no code provision for mix design till now. Therefore the methods which have been employed by researchers frequently in the past to design the mix have been used in this study. A preliminary study has been carried out to understand the basic design method of developing the GPC mix. By using NDT Techniques viz., Digital Rebound hammer, the compressive strength of GPC cubes are tested. Different grades of geopolymer concrete (M30, M40 & M50) of varying molarity viz., 8M and 10M are prepared and the size of the cube was taken as 150×150×150mm. And it was cured in Ambient & Oven conditions. The cubes are tested 28days in compression testing machine. And NDT test (Schmidt Rebound hammer) was carried out on each cube before testing the cube by CTM, totally 10 readings were taken on each cube and the values were recorded in the Schmidt rebound hammer & further compression test was carried. Since these two tests were conducted to compare the compression strength by both DT and NDT methods. The calibration and Regression curves for all the grades of GPC were plotted. The steps involved in the methodology process are shown in Fig 2.

8. MIXING OF GEOPOLYMER CONCRETE

The mixing process involves two stages, dry mix and wet mix [12]. Coarse aggregate, fine aggregate, and GGBS will be mixed initially in rotating pan mixer for 3 to 5 minutes. The alkaline solution is prepared by mixing sodium hydroxide (NaOH) solution with sodium silicate solution (Na_2SiO_3) 24 hours before making the geopolymer concrete. The alkaline solution, extra water and superplasticizer should be pre mixed thoroughly and then added to the dry mixture. The wet mixing of GPC can be done for 2 to 3 minutes [4]. The process of mixing of geopolymer concrete is shown in Figure 4.

TABLE 5 ADOPTED MIX DESIGN PROPORTIONS FOR M30, M40 & M50

Sl.No.	Quantities (kg/m³)	M30	M40	M50
1	GGBS	362	386	410
2	Fine aggregate (coarse sand)	682.6	618.5	554.4
3	Coarse aggregate (20 mm)	710.64	743.4	776.16
4	Coarse aggregate (12.5 mm)	473.76	495.6	517.44
5	Sodium silicate (Na_2SiO_3)	116.36	116.8	117.14
6	Sodium hydroxide (NaOH)	46.54	46.7	46.86
7	Molarity of NaOH	8M	10M	10M
8	Extra water	45	33	45

Fig. 2 Flowchart for methodology

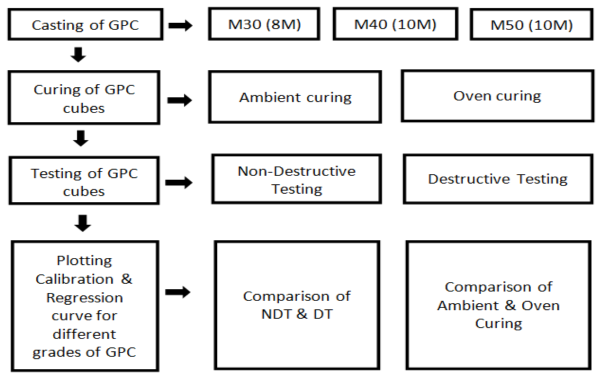

Fig. 3 Cast GPC Cubes

9 RESULTS AND DISCUSSIONS

9.1 Compressive Strength

The compressive strength of GPC mixes (M30, M40, & M50) at 28 days and at different curing conditions is presented in Table 6. To compare the compressive strength of GPC by both destructive and non destructive testing method, the SRH test was done before testing cube by CTM. The detailed test results of each cube for all the grades of GPC mixes (M30, M40 & M50) at different curing conditions at the age of 28 days are presented in Table 7.

From Table 6 & 7, the results show that the compressive strength obtained for GPC cubes cured in oven curing temperature will give higher strength as compared to GPC cubes cured in ambient temperature. This is due to the fact that, the dissolution of silica and alumina in alkaline solution is better at higher temperature [1]. The same pattern was observed with the rebound number. Also, it was observed that the compressive strength is slightly increased with the age of concrete. The Figures 5-10 shows the variation of compressive strength by NDT and DT methods at 28days curing period for all the grades of GPC for different curing conditions.

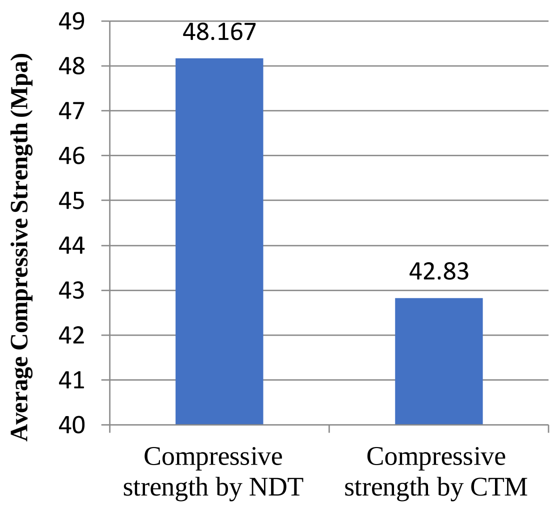

Fig. 5 Average compressive strength of M30 grade GPC at Ambient curing condition.

The calibration curve for compressive strength versus rebound number for each grade of GPC is shown in Fig. 11-13, from the calibration curve the following equation is obtained. These equations represent the relationship between rebound number and compressive strength of GPC. The various equations for all the grades of GPC are presented in Table 8.

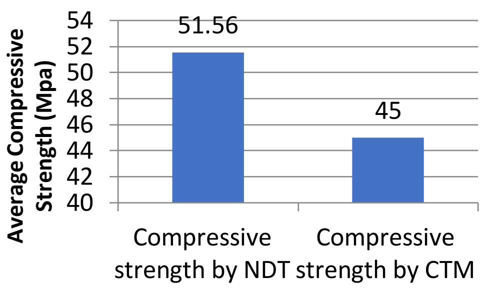

Fig. 6 Average compressive strength of M30 grade GPC at Oven curing condition.

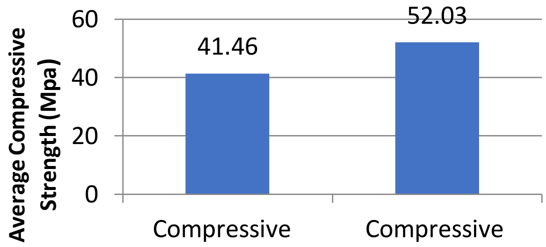

Fig. 7 Average compressive strength of M40 grade GPC at Ambient curing condition

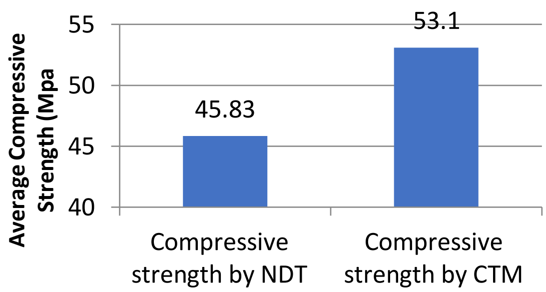

Fig. 8 Average compressive strength of M40 grade GPC at Oven curing condition

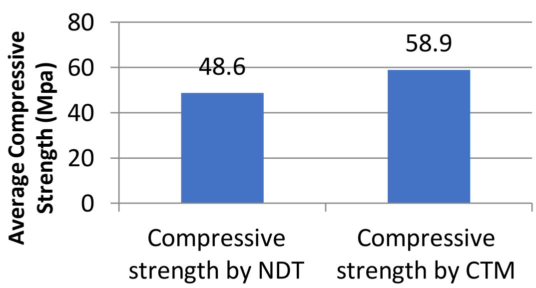

Fig. 9 Average compressive strength of M50 grade GPC at Ambient curing condition

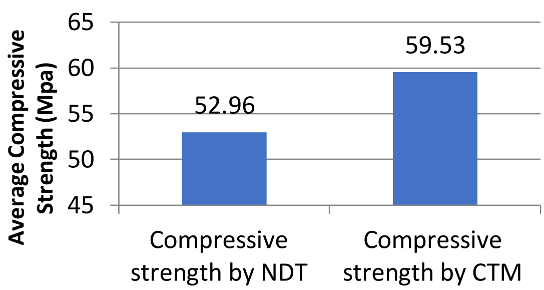

Fig. 10 Average compressive strength of M50 grade GPC at Oven curing condition

In Table 8, y represents the compressive strength by NDT and x represents the rebound number. The number of data used in the correlation n = 10. The R^2 value for different grades of GPC was ranging from 93-100%, which represents a significant correlation. While the R^2 value for oven cured specimen is nearer to 100% as compared to ambient cured specimen. Hence NDT method for GPC will be more suitable for oven cured specimen as compared to ambient cured specimen.

Table 8.Relationship between rebound number & compressive strength equations for different grades of GPC

Grade of GPC	Method of Curing	Age (days)	y	R^2
M30	Ambient curing	28	4.718x – 194.97	0.9325
	Oven curing	28	3.5365x – 130.45	0.9997
M40	Ambient curing	28	0.8028x – 5.4141	0.9987
	Oven curing	28	9.2857x – 518.74	0.9922
M50	Ambient curing	28	0.5466x + 17.373	0.9838
	Oven curing	28	0.9877x – 6.559	0.9637

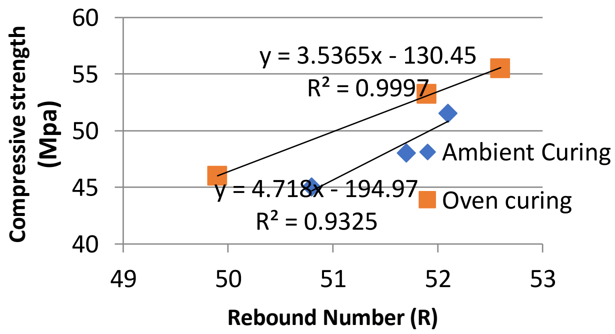

Fig. 11 Calibration Curve for M30 grade GPC

Table 6.Compressive strength results of GPC by both methods

Grade of GPC	Method of Curing	Age (days)	Rebound Number (R)	Compressive strength by NDT (Mpa)	Compressive strength by CTM (Mpa)	Percentage difference of hammer test with destructive test
M30	Ambient Curing	28	50.8	45	42.1	-6.88
			51.7	48	42.9	-11.88
			52.1	51.5	43.5	-18.39
	Oven Curing	28	49.9	46	44.3	-3.83
			51.9	53.2	45.1	-17.96
			52.6	55.5	45.6	-21.71
M40	Ambient Curing	28	57.2	40.5	51.7	21.66
			58.9	41.9	52.1	19.57
			59.1	42	52.3	19.69
	Oven Curing	28	60.5	43	52.5	18.09
			60.9	47	53.1	11.48
			61	47.5	53.7	11.54
M50	Ambient Curing	28	56.3	48.1	58.6	17.91
			57	48.6	58.9	17.48
			58.1	49.1	59.2	17.06
	Oven Curing	28	59.4	52	59.3	12.31
			60.2	53.1	59.5	10.75
			61.2	53.8	59.8	10.03

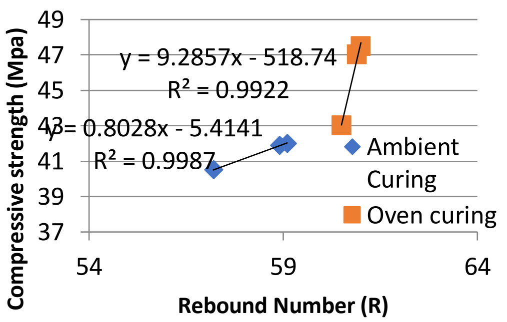

Fig. 12 Calibration Curve for M40 grade GPC

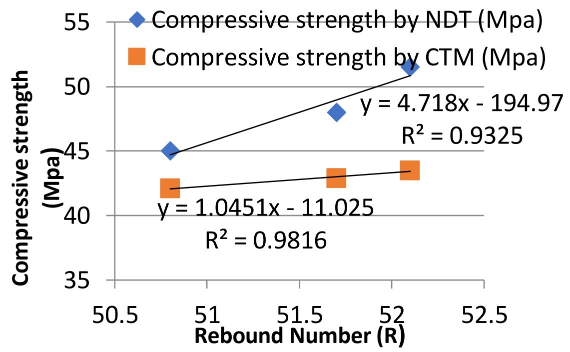

Fig. 14 Regression curve for M30 grade GPC cured in ambient condition

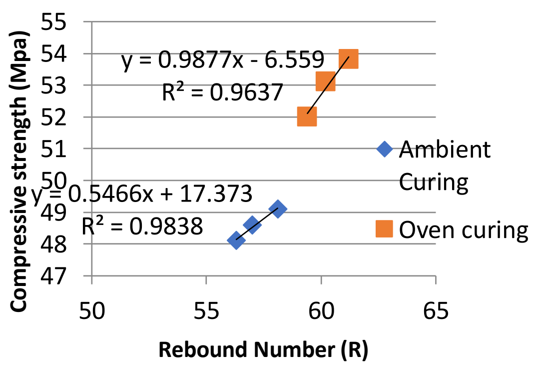

Fig. 13 Calibration Curve for M50 grade GPC

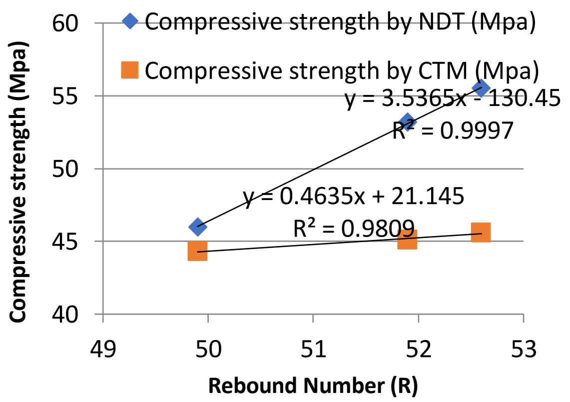

Fig. 15 Regression curve for M30 grade GPC cured in Oven condition

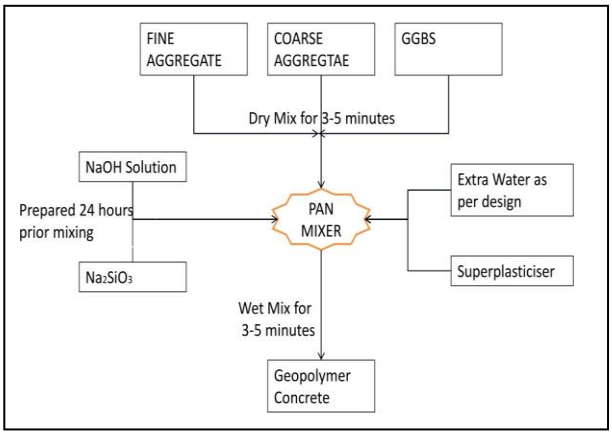

Fig. 4 Mixing Process of Geopolymer Concrete (Shabarish V. Patil 2018[4])

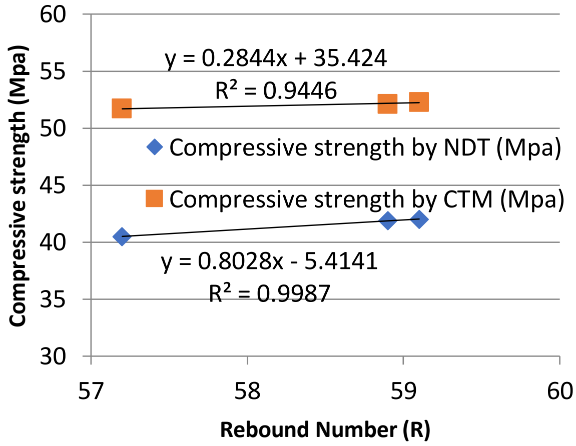

Fig. 16 Regression curve for M40 grade GPC cured in ambient condition

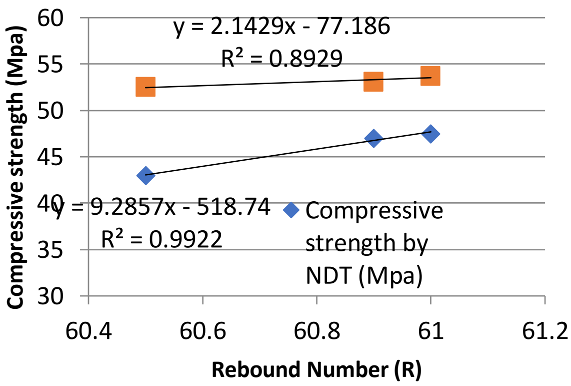

Fig. 17 Regression curve for M40 grade GPC cured in Oven

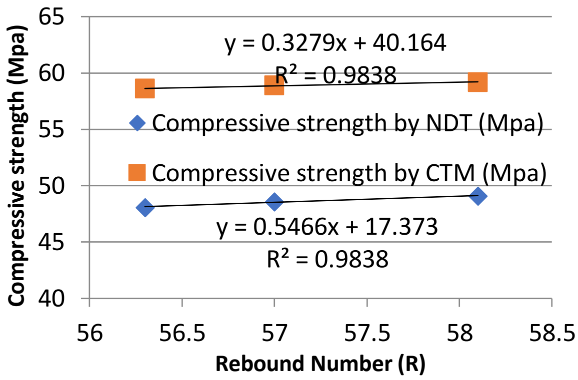

Fig. 18 Regression curve for M50 grade GPC cured in ambient condition

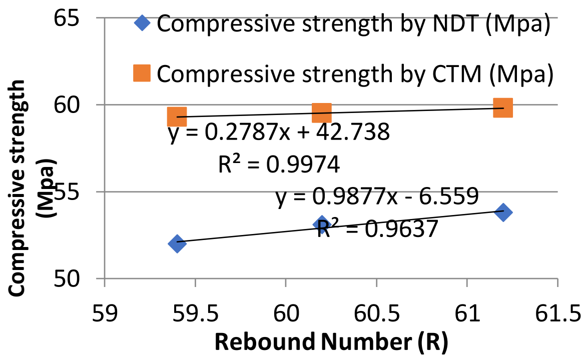

Fig.19 Regression curve for M50 grade GPC cured in Oven condition

10. CONCLUSION

Based on the experimental investigation, the following conclusions have been made,

- The compressive strength of oven cured geopolymer concrete is more as compared to ambient cured irrespective of the age of concrete.
- The compressive strength values for all the grades of GPC by the Non-destructive test were less than the destructive test.
- From the results, the percentage difference of error between the Non-destructive testing and destructive testing method was found to be ±25%. Hence by using SRH method strength prediction can be made up to an accuracy of ±25%. This is also indicated in standard code.
- From the regression analysis, it is clear that he NDT method for GPC will be more accurate for oven cured specimen as compared to ambient cured specimen.
- From the calibration curves, the approximate relationship between rebound number and compressive strength can be obtained for future analysis.

Table 7.Detailed test results of GPC by NDT and DT

Grade of GPC	Method of Curing	Age (days)	Compressive strength of specimen by NDT (MPa)			Compressive strength of specimen by CTM (MPa)			Rebound number of each specimen		
M30	Ambient Curing	28	45	48	51.5	42.1	42.9	43.5	50 54 53.5 54 49 48 51.5 50 48 50	51 52 49.5 54.5 47.5 52 51 53.5 54 52	52.5 53 51 50.5 52 49 51 51.5 57.5 53
	Oven Curing	28	46	53.2	53.5	44.3	45.1	45.6	49 52 52 50.5 48.5 52.5 48 48 51 47.5	51 52 49.5 54.5 47.5 53 51 54 54 52.5	51 52 49.5 54.5 49 53.5 52.5 55 54 55
M40	Ambient Curing	28	40.5	41.9	42	51.7	52.1	52.3	54.5 58 59 57 56.5 59 57 57.5 57 56	52 55 56 58.5 62 63 62 57.5 63.5 59.5	57 57 61 61.5 59.5 61 57.5 55 61 60
	Oven Curing	28	43	47	47.5	52.5	53.1	53.7	60.5 64.5 64 61.5 61.5 58.5 59 57 60.5 58	65 56 60 58 63 59 62 61 60 65	64 60 60.5 61.5 59.5 61 61.5 59 61 61
M50	Ambient Curing	28	48.1	48.6	49.1	58.6	58.9	59.2	54 54 54.5 60.5 58.5 55 55.5 58.5 57.5 55	54 58 59 57 56 59 57 57 57 56	56 60 59 57 58 59 60 58.5 57.5 56
	Oven Curing	28	52	53.1	53.8	59.3	59.5	59.8	58 64 53 58 61 55 63 61 59 62	60.5 64.5 64 61.5 60.5 57 59 57 60 58	63 64.5 66 61.5 60.5 58.5 60.5 59.5 60 58

REFERENCES

[1]. Shabarish Patil, Vineethraj Math, Rajatkumar Vaidya, Ishwargouda Patil. 2019. Experimental Study on Suitability of Geopolymer Concrete Paver on Medium Traffic Condition Highway. Int. J. Adv. Sci. Eng. 5(3) 975-981.

[2]. C. Sreenivasulu, J. Guru Jawahar &C. Shashidhar. 2018. Predicting Compressive Strength of Geopolymer Concrete using NDT techniques. Asian Journal of Civil Engineering. 19:513-525.

[3]. P. Mahalakshmi, S. Christi, G. Mahalakshmi, J. Nithya. 2018. Investigation on Influence of Size of the Aggregate in Flyash and GGBS Based Geopolymer Concrete with Complete Replacement of River Sand by M-sand. International journal of Innovative Research in Science Engineering and Technology. 7(5), 333-342

[4]. Shabarish Patil, Veeresh Karikatti and Manojkumar Chitawadagi. 2018. Granulated Blast-Furnace Slag (GGBS) based Geopolymer Concrete – Review. Int. J. Adv. Sci. Eng. 5(1) 879-885.

[5]. J Bhattacharjee., 2017, Concrete structures repair rehabilitation and retrofitting, first ed. CBS Publications, India, pp. 51-53.

[6]. Abhishek, B., Chouhan, R. K., Manish, M., & Amritphale, S. S. 2015. Fly ash based geopolymer concrete a new technology towards the greener environment – Review. International Journal of Innovative Research in Science, Engineering and Technology. 4(12) 12178–12186.

[7]. A.Maria Rajesh, M.Adams Joe, Roy Mammen. Study of the Strength Geopolymer Concrete with Alkaline Solution of Varying Molarity. International organization of Scientific Research Journal of Engineering (IOSRJEN) 4(6) 2278-8719 (2014) 2278.

[8]. Jain, A., Kathuria, A., Kumar, A., Verma, Y., & Murari, K. 2013. Combined use of non-destructive tests for assessment of strength of concrete in structure. Procedia Engineering, 54, 241–251.

[9]. Aminul, L. I., & Rajan, B. 2012. Effect of plasticizer and superplasticizer on workability of fly ash based geopolymer concrete. Proceedings of International Conference on Advances in Architecture and Civil Engineering, 2, 974–977.

[10]. Ganapati Naidu, P, A.S.S.N. Prasad, S. Adiseshu, P.V.V. Satayanarayana 2012. A Study on Strength Properties of Geopolymer Concrete with Addition of G.G.B.S. International Journal of Engineering Research and Development 2(4) 19-28.

[11]. Kong, D. L. Y., & Sanjayan, J. G. 2012. Effect of elevated temperatures on geopolymer paste, mortar and concrete. Cement and Concrete Research, 40(2), 334–339.

[12]. Nuruddin, M. F., Kusbiantoro, A., Qazi, S., Darnawan, M. S., Husin, N. A., 2011. Development of Geopolymer Concrete with Different Curing Conditions. IPTEK, The Journal for Technology and Science, 22(1) February 2011.

[13]. Supraja, V., & Kanta Rao, M. 2011. Experimental study on geopolymer concrete incorporating GGBS. International Journal of Electronics, Communication & Soft Computing Science and Engineering, 2(2), 11–15.

[14]. Rangan, B. V. 2008. Mix Design and Production of Fly ash-based geopolymer concrete. Indian Concrete Journal 82:7-15.

[15]. Hardjito, D., Rangan, B. V., 2005. Development and Properties of Low-Calcium Fly ash-Based Geopolymer Concrete, Research Report GC 1, Curtin University of Technology, Perth, Australia.

[16]. Hardjito, D., & Wallah, S. 2002. Study on engineering properties of fly ash-based geopolymer concrete. Journal of the Australian Ceramic Society, 38(1), 44–47.

[17]. Malhotra, V. M. 1999. Making concrete greener with fly ash. Concrete International, 21(5), 61–66.

[18]. IS 13311-2. 1992. Method of non-destructive testing of concrete methods of test, part 2: rebound hammer. New Delhi: Bureau of Indian Standards.

[19]. IS 516. 1959. Indian standard code of practice methods of test for strength of concrete. New Delhi: Bureau of Indian Standards.